Reliability and Qualification of Wide Bandgap Automotive Power Semiconductors

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Tutorial Objectives:

Wide bandgap devices are increasingly penetrating the automotive market and are becoming prime candidates for implementation in applications like traction inverters or battery chargers. The mission profile of the traction inverter is a particularly aggressive one since the electrothermal stresses on the power devices vary significantly in amplitude and frequency as the motor drive goes through various stages of the drive cycle including acceleration, deceleration, stalling etc. Historically, the traction converter has been implemented using silicon devices where the performance and reliability is well known and understood. Application of WBG devices like SiC MOSFETs and GaN power devices in automotive applications requires understanding of the reliability and qualification procedures especially according to the automotive standard. SiC and GaN power devices have varying internal physics and modes of operation with vastly varying robustness and reliability performance compared to silicon devices. Given the sensitive nature of the application, these devices must pass stringent automotive reliability tests and guidelines defined by the Automotive Electronics Council (AEC), the Joint Electron Device Engineering Council (JEDEC-JC70) and the European Centre of power electronics (AQG). The objectives of this tutorial are

i) Introduce the reliability and robustness requirements of automotive power devices.
ii) Understand the role of packaging and how it affects electrothermal and thermo-mechanical performance.
iii) Understand the physics of degradation and failure of power devices.
iv) Understand the peculiarities of robustness and reliability in WBG devices (SiC and GaN).
v) Understand test methods and circuits used in assessing the reliability and robustness of power devices.

Target Audience:

This tutorial covers a wide breadth of topics ranging from power device physics, technology and automotive applications. It is intended for

a. Academic and industrial researchers with basic and intermediate knowledge of power semiconductors
b. Vehicle engineers seeking to understand reliability testing and qualification of automotive semiconductors and wide bandgap devices.
c. Master's and PhD level researchers seeking to gain practical understanding of reliability and qualification of power semiconductor devices.

Topical Outline:

T1: Introduction to Automotive Semiconductors: (Estimated time: 60 minutes)

a. Automotive Semiconductors Timeline
b. Charging and Traction Converters
c. Silicon Automotive Devices
d. Emergence of WBG Devices
e. Questions

T2: Device and Package Requirements: (Estimated time: 60 minutes)

a. Device Characteristics and electrical degradation
b. Packaging Types and Packaging Materials
c. Thermal Impedance and packaging degradation
d. Introduction to Reliability and Qualification Physics
e. Questions

T3: Electrical Robustness Testing (Estimated time: 60 minutes)

a. Short circuit testing.
b. Unclamped Inductive Switching Measurements
c. Surge Current Testing
d. 3rd quadrant switching and robustness.
e. Questions

T4: Testing and Qualification for Automotive Semiconductors (Estimated time: 75 minutes)

a. Automotive standards and guidelines (AQG, AEC101 and JEDEC)
b. Device and Module Characterization Tests
c. Enviromental Testing (Thermal shock. Vibration, Mechanical Shock)
d. Lifetime Testing (HTGB, HTRB, PC, HTS, HTRB, HTGB)
e. Questions

T5: Peculiarities of WBG Device Characterization and Qualification (Estimated time: 60 minutes)

a. Threshold Voltage Instability and Threshold voltage measurement
b. Bipolar degradation
c. Dynamic On-state resistance
d. Questions

T6: Conclusions and Final discussion with attendees (Estimated time: 30 +15 minutes)

Provisional Schedule of the Tutorial:

Schedule:
9:00- 12:00: T1/T2/T3 (Morning session)
12:00 - 13:00: Lunch Break
13:00 - 16:00: T4/T5/T6 (Afternoon Session)
The proposed schedule can be adapted to include a coffee break in the morning session and afternoon session.

About the Lecturers:

Layi ALATISE is currently a Professor and Royal Society Industry Fellow in Power Electronics at the University of Warwick. He received the B.Eng. (first class Hons.) degree in electrical/electronic engineering and the Ph.D. degree in microelectronics and semiconductors from Newcastle University, Newcastle upon Tyne, U.K., in 2005 and 2008, respectively. In June 2008, he joined the Innovation R&D Department, NXP Semiconductors, as Development Engineer where he designed, processed, and qualified discrete power trench MOSFETs for automotive applications and switched-mode power supplies. In November 2010, he joined the University of Warwick as Science City Research Fellow to investigate advanced power semiconductor materials and devices for improved energy conversion efficiency. Since February 2019, he has been a Professor in Electrical Engineering with the University of Warwick, Coventry, U.K. He has led several EPSRC projects in Power Electronics and is currently working on an UK government funded Project with a major automotive manufacturer for the development of automotive powertrains based on Silicon Carbide traction inverters. He was a recipient of the 2021 best paper award in the IEEE Transactions in Industrial Electronics. He has the authored or co-authored more than 100 publications in journals and international conferences. Prof. Alatise is a Chartered Engineer, Fellow of the IET and a Senior member of the IEEE.

Jose ORTIZ GONZALEZ is currently an Associate Professor at the University of Warwick (UK). He has worked Research Fellow in several EPSRC and Innovate UK projects at Warwick (UK) and the University of Vigo (Spain). His expertise is in power semiconductor device characterisation, reliability and condition monitoring in Power Electronics. He received his PhD from the University of Warwick in December 2017 and is the author of more than 120 journal and conference papers. Jose has developed novel methodologies for assessing the threshold voltage instability of Silicon Carbide and Gallium Nitride power devices and together with professor Alatise, they were awarded the 2021 IEEE Transactions on Industrial Electronics Outstanding Paper Award for the journal article "Performance and Reliability Review of 650 V and 900 V Silicon and SiC Devices: MOSFETs, Cascode JFETs and IGBTs". Jose was a Researcher Co-Investigator on a major £1.2M EPSRC project and has worked in several collaborative research projects. He was part of the online training initiative Powerful Knowledge, together with Electronic Minds. He is an associate editor of Elsevier Microelectronics Reliability. Dr Ortiz Gonzalez a member of the Education Committee of the IEEE Transportation Electrification Community, the secretary of IEEE PELS – TC-6: Emerging Power Electronic Technologies and the secretary of the IEEE IAS Power Electronics Devices and Components Committee.